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A program and documentation for simulation of a **tracked feller/buncher**

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A PROGRAM AND DOCUMENTATION FOR SIMULATION OF A TRACKED FELLER/BUNCHER

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Computer modeling of forest harvesting systems has many applications, each requiring a different approach to simulation. Simulations range from technical descriptions of machine components for improving equipment design to overviews of major systems for estimating large-scale changes in productivity. Forestry Sciences Laboratory personnel at Houghton have been involved for the past several years in developing harvesting simulators for use in forest engineering research (Bradley *et al.* 1976, Bradley and Winsauer 1976, 1978, U.S. Department of Agriculture Forest Service 1978).

The purpose of this paper is to present a computer model and documentation for a tracked feller/buncher (fig. 1). The model was developed to provide a detailed study of this machine's operation in the woods during harvesting operations. It allows the user to identify productive and unproductive conditions, to experiment with ways of increasing machine efficiency, to predict the effects of system changes, and to determine harvest costs for various types of stands and conditions.

THE EQUIPMENT STUDIED

The feller/buncher is a tracked vehicle with a shear mounted on the end of a rotatable hydraulic boom. The shear head can either sever and bunch single stems or accumulate several stems at once. The boom enables the feller/buncher to shear trees up to the boom's maximum reach while maintaining a fairly straight path through the woods; cutting a strip for thinning or in working the face of a clearcut stand.

MODEL OBJECTIVES

The model was designed to study the productivity and operation of the feller/buncher in the woods. Input required includes data on the machine's operating characteristics, the stand itself, and the type of harvest to be carried out.

Model output includes productivity figures such as number of trees, weight and volume harvested per hour or load, number of total cycles (accumulator head loads), number of trees per cycle, total distance traveled, and skid bunches completed.

Additional output includes details of the woods operation, distribution of cycle times, distances, number of trees per bunch, size of skidder bunches, and frequency and length of delays.

Figure 1.—*Tracked feller/buncher.*

SIMULATION LANGUAGE —GPSS

The simulation is written in General Purpose Simulation Language (GPSS), with output subroutines written in FORTRAN. GPSS is a discrete-event simulation language developed by IBM (Schriber 1974). The user constructs a block diagram by arranging the discrete events of a system in their logical structure. The block diagram is made up of a group of specific GPSS block types, which then become the GPSS program. A basic understanding of the GPSS language allows the user to accurately interpret or modify the simulation.

Most versions of GPSS have a standard output format that concisely presents the data. The FORTRAN subroutines are used to present important output values in an organized, labeled form.

MODEL ASSUMPTIONS

The basic time unit used in the model is a "centiminute"— that is, 1/100 of a minute. The feller works one shift a day for the number of days chosen by the user. All volume measures are in 0.01 cu. ft.

The feller/buncher is assumed to operate far enough in advance of the skidder to minimize interactions between machines. To simulate a "hot" logging operation, this model can be combined with a complete skidding-chipping or skidding-loader model. Another alternative would be to add a "black box" skidder segment, a simplified segment used to create the machine interactions without a detailed study of the skidder operation.

Since an efficient skidder load usually contains more trees than the shear can hold, the feller/buncher may shear and drop several loads at one location to create the skidder bunch.

The following assumptions are made about the feller/buncher's behavior:

1. The machine has an accumulating shear. (The model can easily be changed to single-head shear).

2. The feller/buncher travels in a relatively straight row, either along the edge of a clearcut or down a thinning strip, harvesting all trees within reach that are scheduled for cutting. At the end of the strip, it travels through the woods to the next strip, then returns along that strip toward the landing (fig. 2).

3. If there are no more trees within the feller's reach, the bunch it was working on is considered complete and the feller must move forward— it does not back up.

4. If a bunch is not started at a given location (only one accumulator head load has been cut), the feller will carry the trees in the shear head to the next location. (Exception: if the end of the row (strip) has been reached, the feller will drop the load there before traveling to the next strip.

5. The feller/buncher can quit for the day or stop for a break only after completing a bunch for the skidder.

6. Mechanical and nonmechanical delays are incorporated into the model. For ease of programming, they are assumed to occur after the feller/buncher drops the current load of trees.

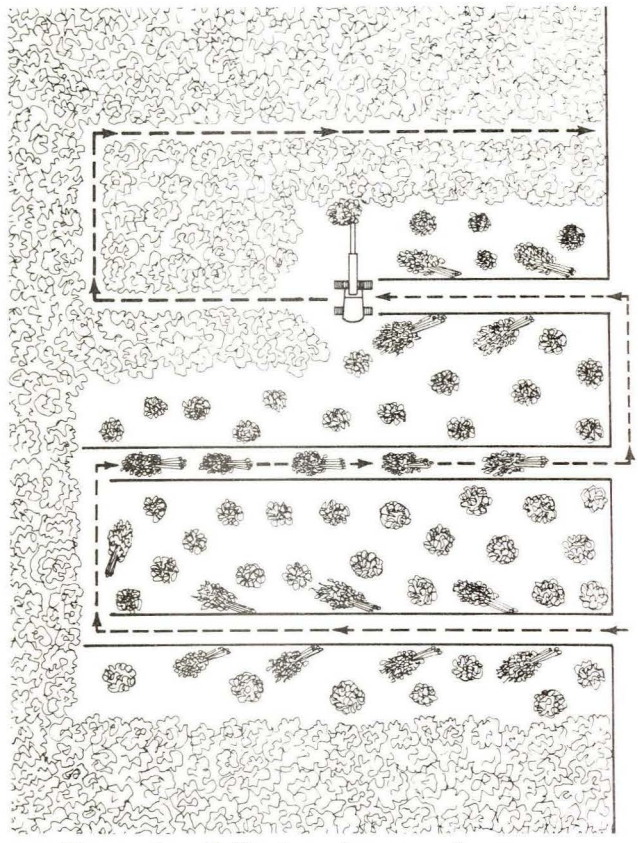


Figure 2.—*Feller/buncher travel pattern.*

MODEL DESCRIPTION

The model consists of two GPSS segments: (1. **Timer segment**, 2. **Feller/buncher segment**) and two FORTRAN subroutines for easily read output. A complete variable list, program listing, and flow charts are contained in Appendixes A, B, and C.

The **Timer segment** (fig. 3) controls the daily schedule, keeps track of the days worked, and sends information to the subroutines. The **Timer** signals the start of the day, the rest breaks and the lunch break (two 15-minute breaks a day and ½ hour lunch break are assumed), and the end of the workday. The **Timer** then completes the 24-hour day and produces a report of the previous day's operation and production. Output is produced at the end of 24 hours— not at the end of the shift— to include the time needed for the feller to complete the bunch being worked on before quitting for the day. If the required number of days has been simulated, the model shuts off. Otherwise the start of another work day is signaled and the process continues.

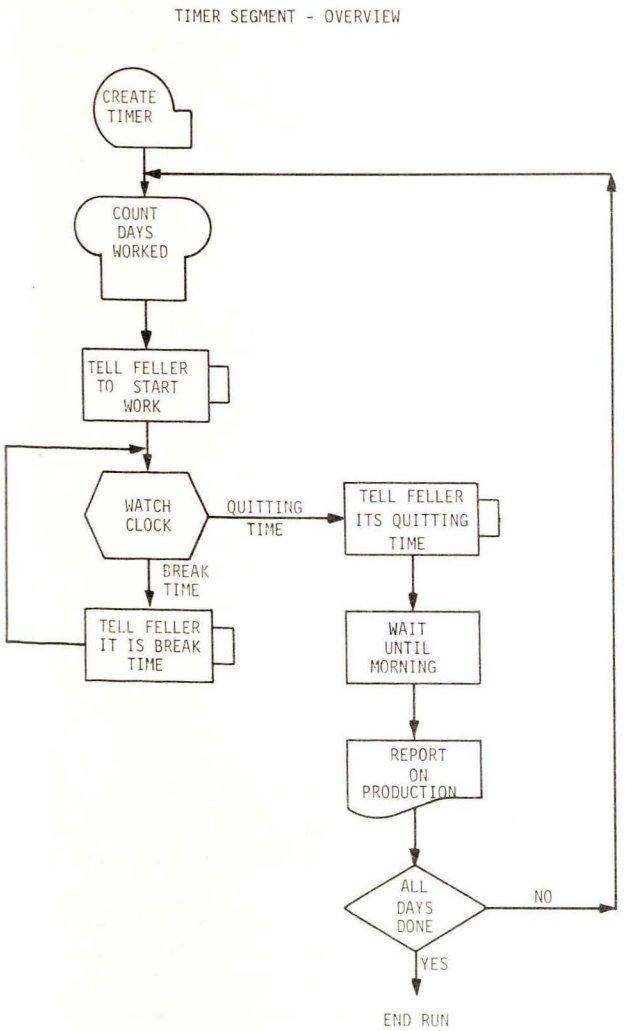


Figure 3.—*Overview of the* **timer segment.**

The **Feller/buncher segment** (fig. 4) simulates a tracked feller/buncher with a boom-mounted shear. This boom enables the machine to remain at a harvesting station while it shears and bunches trees within a radius of 20 feet, (the radius depends on the stand and the harvesting treatment as well as on the physical reach of the boom).

The feller is assumed to move into the woods, cut one or more trees, then drop them to one side to form a bunch. After all the trees to be cut at that location are processed, the feller moves to the next set of trees and repeats the process.

INPUT DATA

GPSS accepts description data in several forms (see table 1). For additional information on data types and card formats, see Appendix D or a GPSS Programming Manual (Schriber 1974).

Most of the data required by this program are needed in the form of VARIABLES. VARIABLES can be defined in terms of the other input types (Appendix D), thus allowing the user flexibility of input data without card shuffling in the main body of the program. For example, a shear-time change from a constant (SAVEVALUE) to a distribution (FUNCTION) can be accomplished by simply redefining the shear-time VARIABLE.

The major exception to this convention is the use of SAVEVALUES (constants) for the summary values (average stand d.b.h., average tree height, etc.) that are used simply for output information.

DATA REQUIRED BY MODEL

Four types of data describing the equipment and harvesting operation must be supplied to run the simulation: (1) stand data (table 2); (2) machine data dependent on stand conditions (table 3); (3) machine data independent of stand conditions (table 4); and (4) simulation run control data (table 5).

The sample output presented in this paper resulted from running the simulation with the input data in tables 2-5. These data were gathered from time studies carried out during actual logging operations. Although the data in the tables may not represent the operating characteristics of the feller/buncher under all conditions, they do present a reasonably accurate picture of its performance in a stand of this type (table 2).

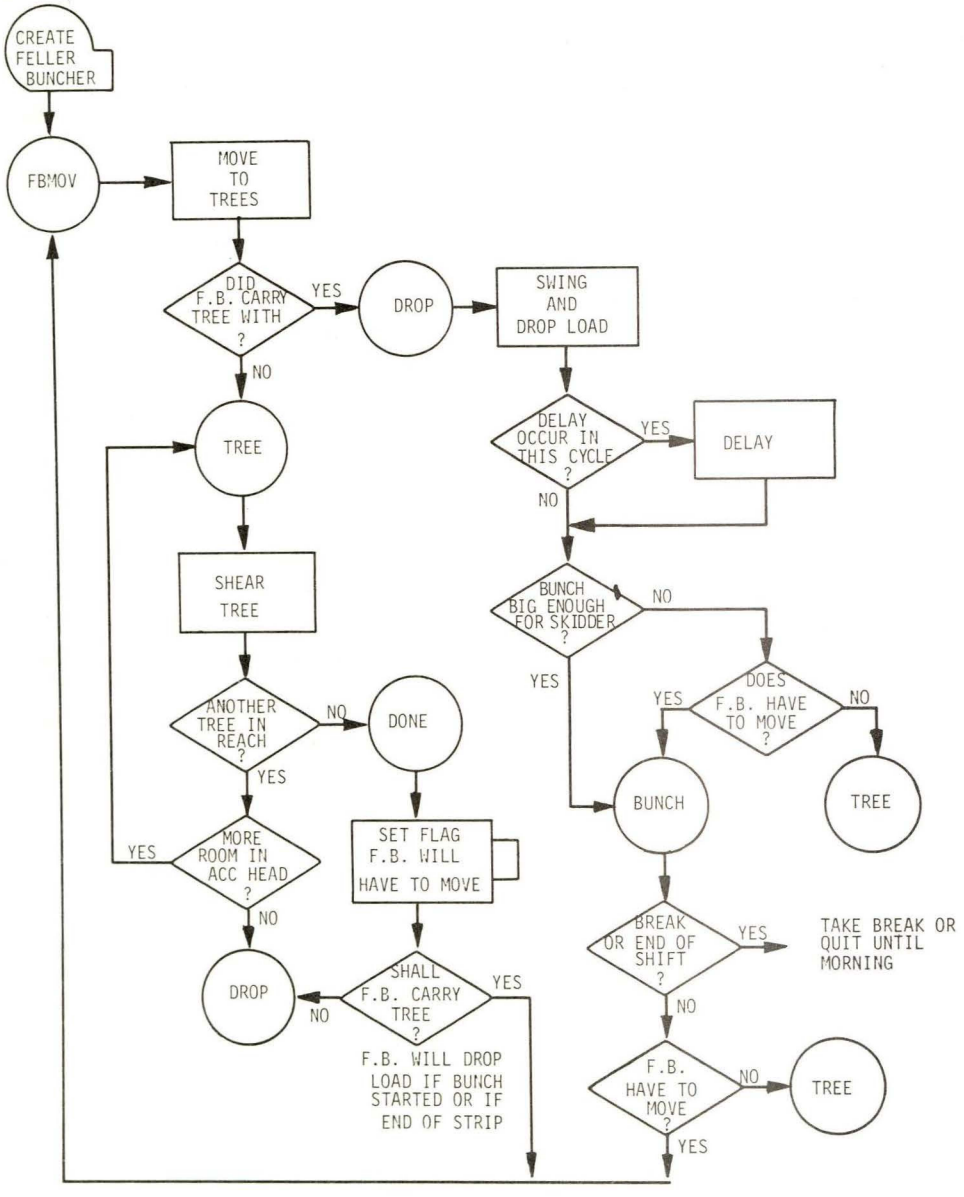


Figure 4.—*Overview of the* **feller/buncher segment.**

SIMULATION OUTPUT

The simulation run produces two pages of labeled output for each day of the run (figs. 5 and 6). These pages contain a summary of the stand data and a cumulative productivity report. Additional output, with complete run details, is produced at the end of the run by the GPSS processor.

The first page of standard output (fig. 7) presents a simulation "map" listing all the blocks in the model and the number of transactions that have moved through each block. This is of primary value while debugging the model. The listing of the QUEUE statistics provides detailed information on how the feller/buncher spends its time in the woods. The SAVEVALUE list contains all the totals necessary to calculate productivity if the FORTRAN subroutines

Table 1.—*GPSS Data input forms*

Input data type	Input form in GPSS	Example
Simple averages or constants	Initialized SAVEVALUES	Ave. d.b.h. = 6 in.
Range of values	Initialized SAVEVALUES for mean and one-half width of interval	Shear time = 10 to 14 centi-min. = 12 ± 2 centi-min.
Equations	VARIABLES	Vol. = .13 d.b.h.^{2} – .28
Frequency distributions	FUNCTIONS	D.b.h.(in.) 4 | 5 | 6 | 7 | 8 percent trees 23 | 25 | 30 | 15 | 5
Mean and variance for a standard distribution such as normal, Poisson Exponential, etc.	SAVEVALUES and FUNCTIONS for the distribution	Wait time is normally distributed with mean = 10 variance = 9

Table 2.—*Stand data*

Data required	Case study	Form required by program	Name
Ave. stand diameter	5.5 in. d.b.h.	SAVEVALUE	X$AVDBH
Ave. stand volume	3,450 cu. ft./acre	SAVEVALUE	X$AVVOL
Ave. tree height	43 ft.	SAVEVALUE	X$AVHGT
Ave. trees/acre	844 trees/acre	SAVEVALUE	X$TRPAC
Strip length	725 ft.	VARIABLE	V$STPLN
Distance between strips	35 ft.	SAVEVALUE	X$MVSTP
Wood density	55 lb./cu. ft.	SAVEVALUE	X$LBCFT
Hours in daily work shift	8 hrs.	SAVEVALUE	X$WKDAY
Actual tree diameters	Diameter distribution: D.b.h.(in.) 3 | 4 | 5 | 6 | 7 | 8 | 9 percent trees 5 | 23 | 30 | 24 | 14 | 3 | 1	VARIABLE	V$TDIA
Tree volume	Volume of trees (cu. ft.): Volume = –0.283 + .0031 (DBH^2) tree ht. = –0.283 + 0.133 (DBH^2) assuming tree ht. = 43 ft.	VARIABLE	V$TVOL

cannot be used. For example:

FBHR = 4020 = feller hours × 100
FBTRE = 6663 trees cut
6663/40.2 = 165.75 trees/hr.

Additional details of the woods operations are provided by the output tables (figs. 8-10). The cycle time table (cycle time starts after the feller/buncher drops one load and ends when it drops the next) shows there were 2,667 cycles with an average cycle time of 79 centi-minutes. Of all cycles, 209 cycles or 7.8 percent took between 100 and 125 centi-minutes.

It should be noted that all of the output is based on random processes in the model. Therefore, the output data are themselves random, only a sample of what could happen. If the model is run again with different random numbers, the results will be different. An average over several days or several runs is the best estimate of an actual system.

Table 3.—*Machine data dependent on stand conditions*

Data required	Case study							Form required by program	Name
Number of trees within reach of accumulator head from a given location	Distribution: trees in head							VARIABLE	V$REACH
	Number of trees	2-4	4-6	6-8	10-12	12-16	16-18		
	percent time	3	7	10	20	20	8		
	Number of trees	18-20	20-22	22-24	24-26	26-30	30-38		
	percent time	7	6	5	4	5	5		
Distance feller must move to be well positioned to cut next set of trees	Distribution: feller travel							VARIABLE	V$FBMOV
	ft.	0-5	5-10	10-25	25-35	35-50			
	percent time	10	15	30	20	10			
	ft.	50-60	60-90	90-120					
	percent time	5	5	5					

```
                    FULL  TREE  FIELD  CHIPPING  SIMULATOR

                                DEVELOPED  BY  THE
                  NORTH CENTRAL FOREST EXPERIMENT STATION
                  FOREST SERVICE, U. S. DEPT. OF AGRICULTURE

          FOREST  PRODUCTS  MARKETING  AND  UTILIZATION  PROJECT,  DULUTH,  MINNESOTA
                                AND  THE
                  FOREST  ENGINEERING  LABORATORY, HOUGHTON, MICHIGAN

                                AUTHORS
                          DENNIS P. BRADLEY, ECONOMIST
                          SHARON A. WINSAUER, PROGRAMMER

I.  STAND CHARACTERISTICS,

     3450,00 CU FT, AVERAGE VOLUME PER ACRE,
        5,50 INCHES, AVERAGE DBH,
       43,00 FEET, AVERAGE TREE HEIGHT,
      884,00 AVERAGE NUMBER OF TREES PER ACRE,
        7,02 FEET, AVERAGE TREE SPACING,

II,  SYSTEM CHARACTERISTICS AS SPECIFIED BY THE ANALYST,
  A,  FELLER-BUNCHER,                    1  MACHINE     TRACKED TYPE-ROTATABLE BOOM WITH ACCUMULATOR SHEAR
       MACHINE LIMITATIONS
         THE ACCUMULATOR-SHEAR WILL TRY TO OBTAIN A LOAD OF UP TO   4,0 TREES
       BUNCH LIMITATIONS DICTATED BY SKIDDER CAPACITY:
         THE FELLER-BUNCHERS TRY TO ACHIEVE SKIDDER BUNCHES WITH A TOTAL SUM OF DIAMETERS EQUAL TO 120,0 INCHES
```

Figure 5.—*Simulation output: system and stand characteristics.*

KNOWN GPSS SYSTEMS DIFFERENCES

The program listed in Appendix B is operational on a UNIVAC 1110 under an implementation of GPSS called GPSS-X8, which can be obtained from Use Program Library Interchange (UPLI). It should run under most GPSS Processors with only minor changes. The following should be checked for your system:

INITIAL cards— In GPSS-X8 the INITIAL cards appear last in the deck. They should be moved to the front of the deck for most other GPSS processors.

Job control cards— These are unique to each com-

Table 4.—*Machine data*

Data required	Case study	Form required by program	Name
Travel time (based on distance)	Travel speed: mean 49 ft./min. s.d. 19 ft./min.	VARIABLE	V$FBTRAV
Shear time per tree	Distribution: shear time time (centi-min.): 0-10 | 10-20 | 20-30 | 30-40 percent of cuts: 29 | 39 | 21 | 8 time (centi-min.): 40-50 | 50-60 | 60-70 | 70-90 percent of cuts: 1 | 1 | .5 | .5	VARIABLE	V$FBSHR
Drop and bunch time per load	Distribution: drop and bunch time time (centi-min.): 1-10 | 10-20 | 20-30 | 30-40 percent of cuts: 3 | 67 | 15 | 3 time (centi-min.): 40-50 | 50-60 | 60-70 percent of cuts: 1 | .5 | .5	VARIABLE	V$FBDRP
Number of trees per accumulator load	Distribution: trees/accumulator head load number of trees: 1 | 2 | 3 | 4 | 5 percent loads: 22 | 23 | 28 | 17 | 10	VARIABLE	V$ACCLM
Maximum size of skidder bunch FB tries to create (total sum of d.b.h.)	120 in.	VARIABLE	V$BUNLM
Gal./hr. fuel used	5.5 gal./hr.	SAVEVALUE	X$FBGPH
Length of nonmechanical delays/cycle (including cycles with zero delay)	Distribution of nonmechanical delays (min.) length of delay: 0 | .15 | .25 | .35 | .40 | .50 | .75 percent of cycles: 98.5 | .2 | .2 | .2 | .1 | .1 | .3 length of delay: .80 | 1.0 | 2.0 | 3.0 | 4.0 | 5.0 percent of cycles: .3 | .3 | .1 | .1 | .1 | .1	VARIABLE	V$NMDLY
Length of mechanical delays/cycle (including cycles with zero delay)	Distribution of mechanical delays (min.) length of delay: 0 | .5 | 1.0 | 1.5 | 2.0 | 2.5 | 5.0 percent of cycle: 99 | .1 | .1 | .1 | .1 | .1 | .1 length of delay: 10.0 | 20.0 | 30.0 | 40.0 percent of cycle: .1 | .1 | .1 | .1	VARIABLE	V$MCDLY

puter lab, and must be obtained locally.

HELP BLOCKS—In GPSS-X8, HELP blocks (lines 65-80 in the program) are used to pass an array of up to five integer values to a FORTRAN subroutine. Only a one-way transfer is permitted; i.e., the subroutine cannot pass arguments back to GPSS. Some versions of GPSS do not allow HELP blocks. In such cases the program can be run without lines 48 to 80; these data can instead be obtained from the standard output. If some form of HELP blocks are allowed, their format and the subroutines may have to be changed. See the GPSS manual for your computer installation.

SENSITIVITY

Table 6 presents the results of a preliminary study of the model's sensitivity. The model was run to fit

Table 5.—*Simulation run control*

Data required	Case study	Form required by program
Random number generators	Random number use 1—used by GPSS scheduler 2—Shear time and drop time distribution 3—trees in reach and distance to move distributions 4—d.b.h. distribution 5—not used 6—delays distribution	RMULT CARD
Number of days	5 days	START CARD
Standard output	every 5th day	

```
      F E L L E R - B U N C H E R   P R O D U C T I O N   A N D   C O S T   S U M M A R Y
*****************************************************************************************

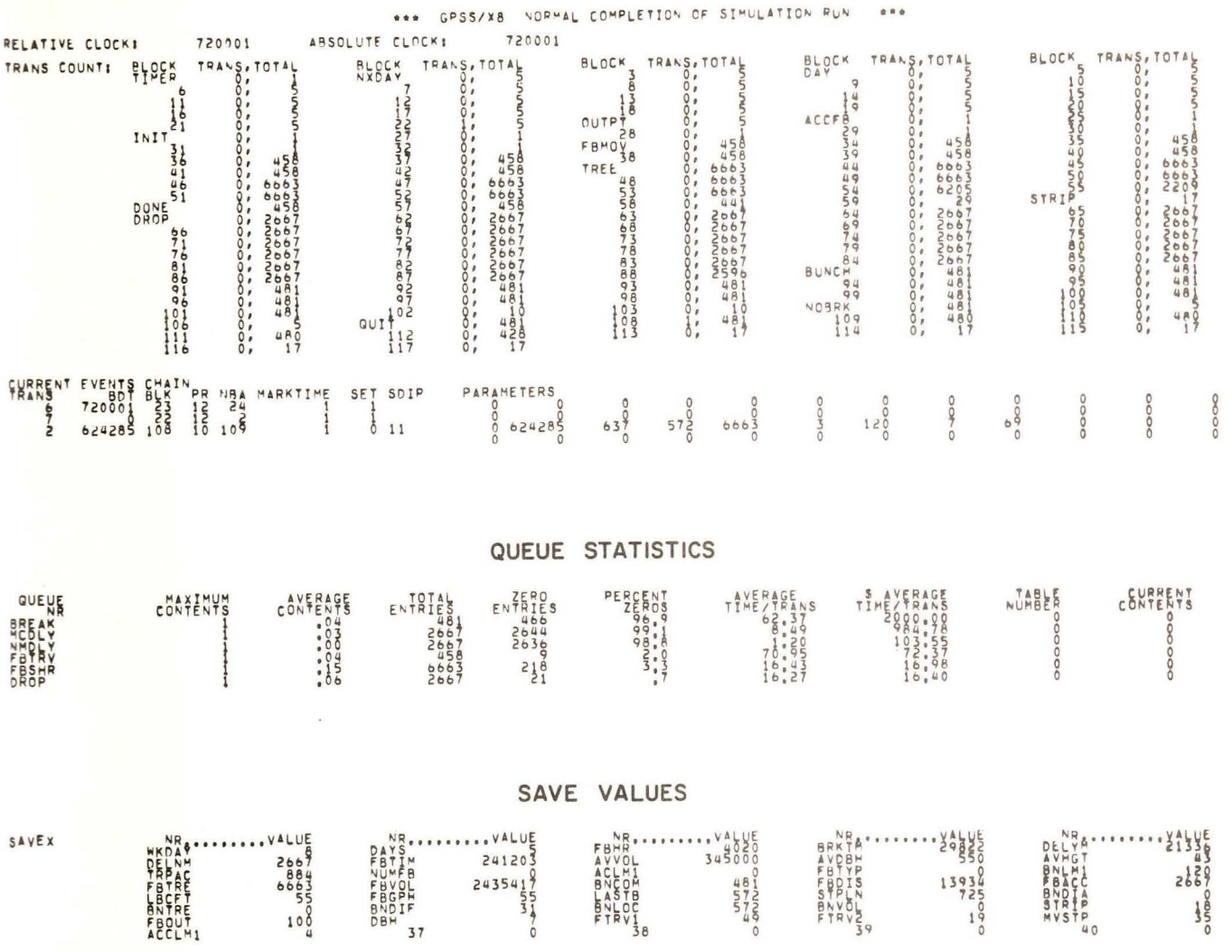
I.    A.   40.20     HOURS WORKED BY FELLER-BUNCHER(S) INCLUDING
                298.22     MINUTES OF PERSONAL BREAKS,
                213.36     MINUTES MECHANICAL DELAY,
                 26.67     MINUTES NON-MECHANICAL DELAY
      B.       1     FELLER-BUNCHER,     TRACKED TYPE-ROTATABLE BOOM WITH ACCUMULATOR SHEAR

II.   A.    2667     TOTAL ACCUMULATOR CYCLES COMPLETED - ALL MACHINES,
                2.50     AVERAGE NUMBER OF TREES PER CYCLE,
                9.13     AVERAGE VOLUME PER CYCLE - CU.FT.
      B.     481     BUNCHES COMPLETED
               13.85     AVERAGE NUMBER OF TREES PER BUNCH,
                5.54     AVERAGE NUMBER OF CYCLES PER BUNCH,
               50.63     AVERAGE VOLUME PER BUNCH - CU.FT.
      C.    6663     TOTAL TREES FELLED,
      D. 24354.2     TOTAL VOLUME FELLED - CU.FT,
      E.  669.74     TOTAL TONS FELLED
      F.   13934     TOTAL DISTANCE TRAVELED - FEET

III.  A.   66.34     AVERAGE NUMBER OF CYCLES PER MACHINE HOUR,
      B.   11.97     AVERAGE NUMBER OF BUNCHES COMPLETED PER MACHINE HOUR,
      C.  165.75     AVERAGE NUMBER OF TREES FELLED PER MACHINE HOUR,
      D.  605.83     AVERAGE VOLUME FELLED PER MACHINE HOUR,
      E.   16.66     AVERAGE NUMBER OF TONS FELLED PER MACHINE HOUR,
      F.  346.62     AVERAGE DISTANCE TRAVELED PER MACHINE HOUR - FEET,

IV.   A.  221.10     TOTAL GALLONS OF FUEL USED BY THE FELLER-BUNCHER,
               5.50     GALLONS PER HOUR,
                .33     GALLONS PER TON,
                .91     GALLONS PER CUNIT,
```

Figure 6.—*Simulation output: productivity.*



*** GPSS/X8 NORMAL COMPLETION OF SIMULATION RUN ***

RELATIVE CLOCK: 720001 ABSOLUTE CLOCK: 720001

TRANS COUNT: BLOCK TRANS, TOTAL

TIMER 0, 1
6 0, 5
11 0, 5
16 0, 5
21 0, 5
INIT 0, 1
31 0, 1
36 0, 458
41 0, 458
46 0, 6663
51 0, 6663
DONE 0, 458
DROP 0, 2667
96 0, 2667
71 0, 2667
76 0, 2667
81 0, 2667
86 0, 2667
91 0, 481
96 0, 481
101 0, 481
106 0, 5
111 0, 480
116 0, 17

NXDAY 0, 5
7 0, 5
12 0, 5
17 0, 5
22 1, 5
27 0, 1
32 0, 1
37 0, 458
42 0, 458
47 0, 6663
52 0, 6663
57 0, 458
62 0, 2667
67 0, 2667
72 0, 2667
77 0, 2667
82 0, 2667
87 0, 2667
92 0, 481
97 0, 481
102 0, 10
QUIT 0, 481
112 0, 428
117 0, 17

3 0, 5
8 0, 5
13 0, 5
18 0, 5
OUTPT 0, 1
28 0, 1
FBMOV 0, 458
38 0, 458
TREE 0, 6663
48 0, 6663
53 0, 6663
58 0, 441
63 0, 2667
68 0, 2667
73 0, 2667
78 0, 2667
83 0, 2667
88 0, 2596
93 0, 481
98 0, 481
103 0, 10
108 1, 481
113 0, 17

DAY 0, 5
9 0, 5
14 0, 5
19 0, 5
ACCFB 0, 1
29 0, 1
34 0, 458
39 0, 458
44 0, 6663
49 0, 6663
54 0, 6205
59 0, 29
64 0, 2667
69 0, 2667
74 0, 2667
79 0, 2667
84 0, 2667
BUNCH 0, 481
94 0, 481
99 0, 481
NOBRK 0, 481
109 0, 480
114 0, 17

5 0, 5
10 0, 5
15 0, 5
20 0, 1
25 0, 1
35 0, 458
40 0, 458
45 0, 6663
50 0, 6663
55 0, 2209
STRIP 0, 17
65 0, 2667
70 0, 2667
75 0, 2667
80 0, 2667
85 0, 2667
90 0, 481
95 0, 481
100 0, 481
105 0, 5
110 0, 480
115 0, 17

CURRENT EVENTS CHAIN

TRANS	BDT	BLK	PR	NBA	MARKTIME	SET	SDIP	PARAMETERS											
6	720001	53	12	24	1	1		0	0	0	0	0	0	0	0	0	0	0	0
7	0	55	15	2	1	1		0	0	0	0	0	0	0	0	0	0	0	0
2	624285	108	10	109	1	0	11	0	624285	637	572	6663	3	120	7	69	0	0	0
								0	0	0	0	0	0	0	0	0	0	0	0

QUEUE STATISTICS

QUEUE NR	MAXIMUM CONTENTS	AVERAGE CONTENTS	TOTAL ENTRIES	ZERO ENTRIES	PERCENT ZEROS	AVERAGE TIME/TRANS	$ AVERAGE TIME/TRANS	TABLE NUMBER	CURRENT CONTENTS
BREAK	1	.04	481	466	96.9	62.37	2000.00	0	0
MCDLY	1	.03	2667	2644	99.1	8.49	984.78	0	0
NMDLY	1	.00	2667	2636	98.8	1.20	103.55	0	0
FBTRV	1	.04	458	9	2.0	70.95	72.37	0	0
FBSHR	1	.15	6663	218	3.3	16.43	16.98	0	0
DROP	1	.06	2667	21	.7	16.27	16.40	0	0

SAVE VALUES

SAVEX

NR	VALUE	NR	VALUE	NR	VALUE	NR	VALUE	NR	VALUE
WKDAY	0	DAYS	5	FBHR	4020	BRKTM	29822	DELYA	21336
DELNM	2667	FBTIM	241203	AVVOL	345000	AVDBH	550	AVMGT	43
TRBAC	884	NUMFB	0	ACLM1	0	FBTYP	0	BNLM1	120
FBTRE	6663	FBVOL	2435417	BNCOM	481	FBDIS	13934	FBACC	2667
LBCFT	55	FBGPM	55	LASTB	572	STPLN	725	BNDTA	0
BNTRE	0	BNDIF	31	BNLOC	572	BNVOL	0	STRIP	18
FBOUT	100	DBH	7	FTRV1	48	FTRV2	19	MVSTP	35
ACCLM1	4	37	0	38	0	39	0	40	0

Figure 7.—*Simulation output: standard GPSS form.*

actual data as closely as possible. Then one parameter at a time was varied and the effect on productivity noted.

These sensitivity figures can be used (1) to give some indication of the accuracy required for the input data (the greater the sensitivity the more accurately that parameter should be specified), and (2) to give an indication of what factors should be further examined for their impact on the machine's productivity.

It should be noted that even parameters which did not show major changes in productivity at the levels of change examined could have larger effects when changed to a greater degree or when combined with other changes. In all cases, the better the input information, the more accurate the output data will be.

CONCLUSION

With the proper choice of input variables, the simulation model can be used to study productivity of feller/ bunchers under a variety of stand or harvesting conditions. It is possible to study the effects of a change in just one parameter or the effects of many changes at the same time. This model can also be combined with a model of skidding and chipping operations to provide productivity information for whole-tree systems.

Perhaps the greatest value of a GPSS model is the ease by which it can be modified to suit the exact requirements of a harvesting system. Although this requires some knowledge of GPSS, it makes simulation an extremely valuable tool.

CYCLE TIME (CENTI-MINUTES)

TABLE FBTIM — ENTRIES IN TABLE 2667 — MEAN ARGUMENT 79.19 — STANDARD DEVIATION 167.70 — SUM OF ARGUMENTS 211203.

UPPER LIMIT	OBSERVED FREQUENCY	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
25	226	8.47	8.5	91.5	.31	-.32
50	837	31.38	39.9	60.1	.63	-.17
75	716	26.85	66.7	33.3	.94	-.02
100	416	15.60	82.3	17.7	1.26	.12
125	209	7.84	90.1	9.9	1.58	.27
150	89	3.34	93.4	6.6	1.89	.42
175	37	1.39	94.8	5.2	2.21	.57
200	31	1.16	96.0	4.0	2.53	.72
225	25	.94	96.9	3.1	2.84	.86
250	20	.75	97.7	2.3	3.16	1.02
275	13	.49	98.1	1.9	3.47	1.17
300	9	.34	98.5	1.5	3.79	1.32
325	5	.19	98.7	1.3	4.10	1.47
350	2	.08	98.8	1.2	4.42	1.61
375	1	.04	98.8	1.2	4.74	1.76
400	2	.08	98.9	1.1	5.05	1.91
425	2	.08	99.0	1.0	5.37	2.06
450	2	.08	99.1	.9	5.68	2.21
475	2	.08	99.2	.8	6.00	2.36
500	2	.08	99.3	.7	6.32	2.51
525	1	.04	99.3	.7	6.63	2.66
550	1	.04	99.4	.6	6.95	2.81
575	1	.04	99.4	.6	7.26	2.96
600	1	.04	99.5	.5	7.58	3.11
OVERFLOW	13	.49	100.0	.0		

VOLUME (CU. FT. x 100) PER ACCUMULATOR HEAD LOAD

TABLE ACCVL — ENTRIES IN TABLE 2667 — MEAN ARGUMENT 913.17 — STANDARD DEVIATION 538.03 — SUM OF ARGUMENTS 2435417.

UPPER LIMIT	OBSERVED FREQUENCY	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
500	767	28.76	28.8	71.2	.54	-.76
1000	861	32.28	61.0	39.0	1.10	-.16
1500	626	23.47	84.5	15.5	1.64	.09
2000	311	11.66	96.2	3.8	2.19	.62
2500	87	3.26	99.4	.5	2.74	.95
3000	15	.56	100.0	.0	3.29	1.48

Figure 8.—*Simulation output: productivity tables (1,*

NUMBER OF TREES PER ACCUMULATOR HEAD LOAD

TABLE ACCTR	ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS
	2667	2.50	1.22	6663.

UPPER LIMIT	OBSERVED FREQUENCY	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
1	706	26.47	26.5	73.5	.40	-1.22
2	685	25.68	52.2	47.8	.80	-.40
3	714	26.77	78.9	21.1	1.20	.41
4	365	13.69	92.6	7.4	1.60	1.23
5	197	7.39	100.0	.0	2.00	2.05

NUMBER OF TREES PER SKIDDER BUNCH

TABLE BTREE	ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS
	481	13.85	6.37	6663.

UPPER LIMIT	OBSERVED FREQUENCY	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
2	2	.41	.4	99.6	.14	-1.86
3	10	2.08	2.5	97.5	.21	-1.70
4	16	3.33	5.8	94.2	.28	-1.55
5	15	3.12	8.9	91.1	.36	-1.39
6	27	5.61	14.6	85.4	.43	-1.23
7	24	4.99	19.5	80.5	.50	-1.08
8	23	4.78	24.3	75.7	.57	-.91
9	25	5.20	29.5	70.5	.65	-.76
10	25	5.20	34.7	65.3	.72	-.60
11	20	4.16	38.9	61.1	.79	-.44
12	28	5.82	44.7	55.3	.86	-.29
13	37	7.69	52.4	47.6	.93	-.13
14	25	5.20	57.6	42.4	1.01	.02
15	18	3.74	61.3	38.7	1.08	.18
16	23	4.78	66.1	33.9	1.16	.33
17	18	3.74	69.9	30.1	1.23	.49
18	16	3.33	73.2	26.8	1.30	.65
19	16	3.33	76.5	23.5	1.37	.80
20	18	3.74	80.2	19.8	1.44	.96
21	16	3.33	83.6	16.4	1.52	1.12
22	16	3.33	86.9	13.1	1.59	1.28
23	21	4.37	91.3	8.7	1.66	1.44
24	18	3.74	95.0	5.0	1.73	1.59
OVERFLOW	24	4.99	100.0	.0		

Figure 9.—*Simulation output: productivity tables (II).*

DISTANCES (FT) BETWEEN CONSECUTIVE BUNCHES

TABLE	ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS
BDIF	481	25.93	27.60	12474.

UPPER LIMIT	OBSERVED FREQUENCY	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
0	58	12.06	12.1	87.9	0.00	-.94
5	54	11.23	23.3	76.7	.19	-.75
10	55	11.43	34.7	65.3	.38	-.57
15	37	7.69	42.4	57.6	.57	-.39
20	51	10.60	53.0	47.0	.77	-.21
25	47	9.77	62.8	37.2	.96	-.03
30	44	9.15	71.9	28.1	1.16	.14
35	26	5.41	77.3	22.7	1.35	.32
40	9	1.87	79.2	20.8	1.54	.51
45	14	2.91	82.1	17.9	1.74	.69
50	17	3.53	85.7	14.3	1.93	.87
55	9	1.87	87.5	12.5	2.12	1.05
60	11	2.29	89.8	10.2	2.31	1.23
65	6	1.25	91.1	8.9	2.51	1.42
70	2	.41	91.5	8.5	2.70	1.60
OVERFLOW	41	8.52	100.0	.0		

VOLUME (CU.FT. x 100) PER SKIDDER BUNCH

TABLE	ENTRIES IN TABLE	MEAN ARGUMENT	STANDARD DEVIATION	SUM OF ARGUMENTS
BVOL	481	5063.24	2341.80	2435417.

UPPER LIMIT	OBSERVED FREQUENCY	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE	CUMULATIVE REMAINDER	MULTIPLE OF MEAN	DEVIATION FROM MEAN
1000	8	1.66	1.7	98.3	.19	-1.74
1500	19	3.95	5.6	94.4	.29	-1.52
2000	18	3.74	9.4	90.6	.39	-1.31
2500	29	6.03	15.4	84.6	.49	-1.09
3000	33	6.86	22.2	77.8	.59	-.88
3500	38	7.90	30.1	69.9	.69	-.66
4000	30	6.24	36.4	63.6	.79	-.45
4500	41	8.52	44.9	55.1	.88	-.24
5000	29	6.03	50.9	49.1	.98	-.02
5500	37	7.69	58.6	41.4	1.09	.18
6000	29	6.03	64.7	35.3	1.19	.40
6500	31	6.44	71.1	28.9	1.28	.61
7000	24	4.99	76.1	23.9	1.38	.82
7500	18	3.74	79.8	20.2	1.48	1.04
8000	17	3.53	83.4	16.6	1.58	1.25
8500	33	6.86	90.2	9.8	1.68	1.47
9000	29	6.03	96.3	3.7	1.78	1.68
9500	13	2.70	99.0	1.0	1.88	1.89
10000	4	.83	99.8	.2	1.98	2.11
10500	1	.20	100.0	.0	2.07	2.32

Figure 10.—*Simulation output: productivity tables (III).*

Table 6.—*Sensitivity of the simulation*

Change in run parameters	Productivity	
	Tons/hr.	Effect
Standard run	16.66	
Decrease shearing time by 10 percent	17.48	Increase 5 percent
Decrease swing & drop time by 10 percent	16.84	([1])
Increase travel speed by 10 percent	16.70	([1])
Increase average number of trees in accumulator head load from 2.5 to 3.5	17.82	Increase 7 percent
Increase average number of trees within reach from 14 to 16	16.72	([1])
Increase average d.b.h. by 1 inch	23.94	Increase 43 percent
Increase frequency of mechanical delay from 1 percent to 2 percent of the cycles	14.64	Decrease 12 percent

[1]No major change in productivity observed for this level of change in parameter.

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APPENDIX A

VARIABLE LISTS AND DEFINITIONS

Definitions

IMPLICIT TIME UNIT— Centi-minute
MODEL SEGMENTS, TRANSACTIONS, AND PARAMETERS

Segment 1—**timer**
Transactions—1 time keeper
Parameters—NONE

Segement 2—**feller/buncher**
Transactions—feller/buncher
Parameters
P1—not currently used.
P2—clock time marking start of cycle.
P3—next location of feller/buncher (distance in feet from the beginning of this strip or row).
P4—current location of feller bunches (distance down strip in feet).
P5—tree number being cut.
P6—limit for trees in accumulator head (number of trees).
P7—maximum size of skidder bunch attempted (sum of diameters).
P8—diameter of current tree.
P9—distance feller/buncher must travel to next set of trees.
P10—number of trees currently within reach of boom.
P11—actual sum of diameter of accumulator load.
P12—total volume in accumulator head.
P13—number of trees in load.

Functions

ACCLM	Distribution of the number of trees in accumulator loads.
DBH	Distribution of diameters in the stand.
FBDRP	Distribution of drop times.
FBMOV	Distribution of the distances feller must move to reach more trees.
FBSHR	Distribution of shear times.
MCDLY	Distribution of mechanical delay times in each cycle (including cycles with zero delay).
NMDLY	Distribution of nonmechanical delay times in each cycle (including cycles with zero delay).
REACH	Distribution of trees within reach from a random spot.
SNORM	Distribution used to obtain a normal distribution for sampling with a mean = 0, variance = 1. Lower end truncated.

Savevalues

ACLM1	Mean accumulator head limit (number of trees).
AVDBH	Mean stand diameter (inches × 100).
AVHGT	Mean stand height (feet).
AVVOL	Mean vol./acre (cu.ft. × 100).
BNCOM	Number of skidder bunches complete and ready for skidding.
BNDIA	Sum of diameters of trees in the bunch (inches).
BNDIF	Distance between bunches (feet).
BNLM1	Limit for skid bunch size— maximum sum of diameters.
BNLOC	Location of bunch (distance from end of strip).
BNTRE	Number of trees in a bunch.
BNVOL	Volume of bunch (cu.ft. × 100).
BRKTM	Total time spent on breaks (centi-minutes).
DAYS	Number of days worked.
DBH	Diameter breast high (d.b.h.) of current tree (inches).
DELNM	Total time lost to nonmechanical delays (centi-minutes).
DELYM	Total time lost to mechanical delays (centi-minutes).
FBACC	Total number of feller/buncher accumulator loads.
FBDIS	Total distance feller/buncher has traveled (feet).
FBGPH	Feller/buncher fuel usage (gal./hr.).
FBHR	Total time feller has worked (hours × 100).
FBOUT	Distance feller travels to get to the woods (feet).

FBTIM	Total time feller has been on job (minutes × 100).
FBTRE	Total trees cut.
FBTYP	Feller/buncher type; tracked = 0, rubber-tired = 1.
FBVOL	Total volume cut (cu.ft. × 100).
FTRV1	Mean travel speed (ft./min.).
FTRV2	Standard deviation of travel speed.
LASTB	Location of last bunch.
LBCFT	Density of plot species (lb./cu. ft.).
MVSTP	Distance feller/buncher travels between strips.
NUMFB	Number of feller/bunchers on the job.
STPLN	Length of strip or row (feet).
STRIP	Number of strips harvested.
TRPAC	Mean stand density (trees/acre).
WKDAY	Length of work shift (hours).

Switches

COFFE	Set by timer to indicate coffee break.
DAY	Set by timer to indicate beginning of work day.
FBMOV	Set by feller when he must move (no more trees in reach).
LUNCH	Set by timer to indicate lunch break.
STRIP	Set by feller/buncher when he has cut the last tree of current strip.

Tables

ACCTR	Trees per accumulator load.
ACCVL	Volume per accumulator load (cu.ft. × 100).
BDIA	Sum of diameter of trees in a skid bunch (inches).
BDIF	Distance between bunches (feet).
BLOC	Bunch location— distance down strip (feet).
BTREE	Number of trees in skidder bunch.
BVOL	Volume per skidder bunch (cu.ft. × 100).
FBTIM	Cycle time for feller/buncher, from drop to drop, including delays (centi-minutes).

Queues

BREAK	Coffee and lunch break time.
DROP	Swing and drop time.
FBSHR	Position and shear time.
FBTRV	All travel time.
MCDLY	Mechanical delays.
NMDLY	Nonmechanical delays.

Variables

ACCLM	Accumulator head size limit (number of trees).
BNDIF	Calculate distance between bunches (feet).
BREAK	Time between breaks (centi-minutes).
BRKTM	Time spent on breaks (centi-minutes).
BUNLM	Skidder bunch limit (sum of diameter).
DELNM	Nonmechanical delay time (centi-minutes).
DELYM	Mechanical delay time (centi-minutes).
FBDRP	Swing and drop time (centi-minutes).
FBHR	Total hours worked.
FBMOV	Distance feller/buncher must move to put more trees in reach (feet).
FBSHR	Shear time (centi-minutes).
FBTRV	Travel time (centi-minutes).
MCDLY	Length of mechanical delay (centi-minutes).
NEXTY	Next harvesting location down strip = current position + 95 percent distance traveled (allows for travel not in a straight line).
NIGHT	Remainder of 24 hours after work shift (centi-minutes).
NMDLY	Nonmechanical delay time (centi-minutes).
REACH	Number of trees within reach of boom at current feller/buncher position.
SPEED	Travel speed (ft./min.).
STEND	Distance to the end of strip (feet).
STPLN	Length of strip or plot (feet).
TDIAM	Tree diameter (inches).
TVOL	Tree volume (0.01 cu. ft.).
WKDAY	Length of work shift (centi-minutes).

APPENDIX B

PROGRAM LISTING

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                /
                *
                * * * *   GENERATE FELLER BUNCHERS,INITIALIZE FIRST DIST,ACCUMULATOR HEAD
                *
24              ACCFB GENERATE    ,,,1,10,15
                *
25                    SAVEVALUE   STRIP,1                 INITIALIZE STRIP COUNT
26               INIT ASSIGN      11,0                    INITIALIZE ACCUMULATOR HEAD
27                    ASSIGN      12,0
28                    ASSIGN      13,0
29                    ASSIGN      6,V$ACCLM               ACC. LOAD LIMIT
30                    ASSIGN      7,V$BUNLM               BUNCH SIZE LIMIT
31                    ASSIGN      9,X$FBOUT               DIST FB TRAVELS TO START WORK
32                    MARK        2                       MARK START OF CYCLE
                *
                * * * * FB MOVES TO NEXT LOCATION,RESETS SWITCH FBMOV,RECORDS
                *          TRAVEL DISTANCE AND TIME AND DETERMINES # OF TREES
                *          WITHIN REACH AT THIS LOCATION.
                *
33              FBMOV QUEUE       FBTRV
34                    ADVANCE     V$FBTRV                 FB MOVES TO NEW LOCATION
35                    DEPART      FBTRV                   RECORD TRAVEL TIME
36                    SAVEVALUE   FBDIS+,P9                       AND DISTANCE
                *
37                    ASSIGN      10,V$REACH              DETERMINE # OF TREES IN REACH
38                    ASSIGN      4,P3                    ACTUAL DISTANCE DOWN THE STRIP OF
                *                                           THE FELLER BUNCHER
39                    ASSIGN      9,V$FBMOV               DISTANCE FB WILL HAVE TO MOVE
                *                                           WHEN DONE HERE
40                    ASSIGN      3,V$NEXTY               NEXT LOCATION OF FB
41                    LOGIC R     FBMOV                   RESET TO INDICATE FB NOT
                *                                           READY TO MOVE
                *
                * * * * CHECK IF FB HAS CARRIED A TREE TO THIS LOCATION
                *          IF SO GO TO DROP
                *
42                    TEST E      P13,0,DROP              IF # OF TREES IN HEAD > 0 DROP
                *
                * * * * TREE=    FELLER BUNCHER DEFINES AND SHEARS TREES UNTIL ACCUMULATOR
                *                HEAD IS FULL OR UNTIL HE RUNS OUT OF
                *                TREES WITHIN REACH
                *
43               TREE ASSIGN      5+,1                    TREE NUMBER
44                    ASSIGN      8,V$TDIAM               DBH
                *
45                    QUEUE       FBSHR
46                    ADVANCE     V$FBSHR                 SHEAR TREE
47                    DEPART      FBSHR                   RECORD SHEAR TIME
                *
48                    ASSIGN      11+,P8                  TOTAL SUM OF DBH OF LOAD
49                    ASSIGN      13+,1                   # OF TREES IN ACC HEAD
50                    SAVEVALUE   DBH,P8
51                    ASSIGN      12+,V$TVOL              TOTAL VOL OF ACC. LOAD
52                    ASSIGN      10-,1                   ONE LESS TREE IN REACH
                *
53                    TEST G      P10,0,DONE              IF NO MORE TREES HERE GO TO DONE
54                    TEST GE     P13,P6,TREE             IF ACC NOT FULL & A TREE IN REACH
                *                                           GO TO TREE TO CUT IT
55                    TRANSFER    ,DROP                   ACC HEAD FULL GO TO DROP
                *
56               DONE LOGIC S     FBMOV                   SET SWITCH THAT THE FB MUST MOVE
57                    TEST L      P3,V$STPLN,STRIP        IF AT END OF STRIP GO TO STRIP
58                    TEST E      X$BNTRE,0,DROP          IF BUNCH IS ALREADY STARTED,DROP LOAD
                *                                           OTHERWISE,CARRY TREES IN ACC. HEAD
                *                                           ALONG WITH (FBMOV)
59                    TRANSFER    ,FBMOV
60              STRIP LOGIC S     STRIP                   SET SWITCH INDICATING END OF STRIP
                *
```

```
                / * * * DROP-    SWING AND DROP THE FB LOAD, ACCUMULATE LOAD STATISTICS
                *                  SEE IF THE BUNCH IS LARGE ENOUGH FOR SKIDDERS
                *
 61   DROP  QUEUE       DROP
 62         ADVANCE     V$FBDRP                 SWING AND DROP BUNCH
 63         DEPART      DROP                    RECORD SWING & DROP TIME
                *
 64         SAVEVALUE   BNLOC,P4                DISTANCE DOWN STRIP
 65         SAVEVALUE   BNVOL+,P12              TOTAL VOLUME
 66         SAVEVALUE   BNDIA+,P11              TOTAL DIA OF LOAD
 67         SAVEVALUE   BNTRE+,P13              TOTAL NO OF TREES
                *
                * * * * DELAY-    IF A DELAY IS DUE TO OCCUR, IT HAPPENS HERE
                *
 68         QUEUE       MCDLY
 69         ADVANCE     V$MCDLY                 MECHANICAL DELAY
 70         DEPART      MCDLY
 71         QUEUE       NMDLY
 72         ADVANCE     V$NMDLY                 NON-MECHANICAL DELAY
 73         DEPART      NMDLY
                *
 74         SAVEVALUE   FBACC+,1                KEEP TRACK OF NUMBER OF ACC. LOADS
 75         SAVEVALUE   FBTRE+,P13              FB RECORDS PRODUCTION OF
 76         SAVEVALUE   FBVOL+,P12                BOQUETS AND OF TIME
 77         SAVEVALUE   FBTIM+,MP2
 78         TABULATE    FBTIM
 79         TABULATE    ACCVL
 80         TABULATE    ACCTR
 81         MARK        2                       REINITIALIZE ACC HEAD
 82         ASSIGN      11,0
 83         ASSIGN      12,0
 84         ASSIGN      13,0
 85         ASSIGN      6,V$ACCLM               NEW ACCUMULATOR LIMIT
 86         ASSIGN      7,V$BUNLM               NEW BUNCH LIMIT
                *
 87         TEST L      X$BNDIA,P7,BUNCH
                *                                                 TO BUNCH
 88         GATE LS     FBMOV,TREE                        IF MORE TREES IN REACH-
                *                                           GO TO TREE FOR
                *                                           ANOTHER ACC. LOAD
                *
                * * * * BUNCH-    TABULATE BUNCH DATA TO USE FOR SKIDDERS,REINITIALIZE
                *                  PARBN MATRIX ,CHECK IF FB IS AT END OF STRIP
                *
                *
 89   BUNCH TABULATE    BDIA                    RECORD BUNCH DATA FOR SKID SEG
 90         TABULATE    BTREE
 91         TABULATE    BVOL
 92         TABULATE    BLOC
                *
 93         SAVEVALUE   BNDIF,V$BNDIF           DISTANCE BETWEEN BUNCHES
 94         TABULATE    BDIF
 95         SAVEVALUE   LASTB,P4
 96         SAVEVALUE   BNVOL,0                 REINITIALIZE BUNCH DATA
 97         SAVEVALUE   BNDIA,0                   FOR NEXT BUNCH
 98         SAVEVALUE   BNTRE,0
 99         SAVEVALUE   BNCOM+,1                IF TIME FOR COFFEE OR LUNCH,
                *                                  TAKE BREAK
100         QUEUE       BREAK
101         GATE LS     COFFE,NOBRK              CHECK IF BREAK
102         ADVANCE     1500                     15 MINUTE COFFEE BREAK
103         LOGIC R     COFFE
104  NOBRK  GATE LS     LUNCH,QUIT
105         ADVANCE     3000                     30 MINUTE LUNCH BREAK
106         LOGIC R     LUNCH
                *
                * * * * QUIT-    TABULATE TIME ON BREAKS AND CHECK IF
                *                  IT'S TIME TO QUIT FOR THE DAY
                *
107  QUIT   SAVEVALUE   FBTIM+,MP2               TABULATE TIME SPENT ON BREAK
108         DEPART      BREAK
109         GATE LS     DAY                     IF SHIFT IS OVER, STOP UNTIL TOMORROW
110         MARK        2                       MARK START OF CYCLE
111         GATE LS     FBMOV,TREE              MORE TREES IN REACH -GO TO TREE
112         GATE LS     STRIP,FBMOV             IF NOT END OF STRIP -GO TO FBMOVE
                *
113         ASSIGN      3,V$STEND               STRIP DISTANCE
114         SAVEVALUE   LASTB,0
115         SAVEVALUE   STRIP+,1                COUNT STRIPS
116         LOGIC R     STRIP
117         TRANSFER    ,FBMOV
```

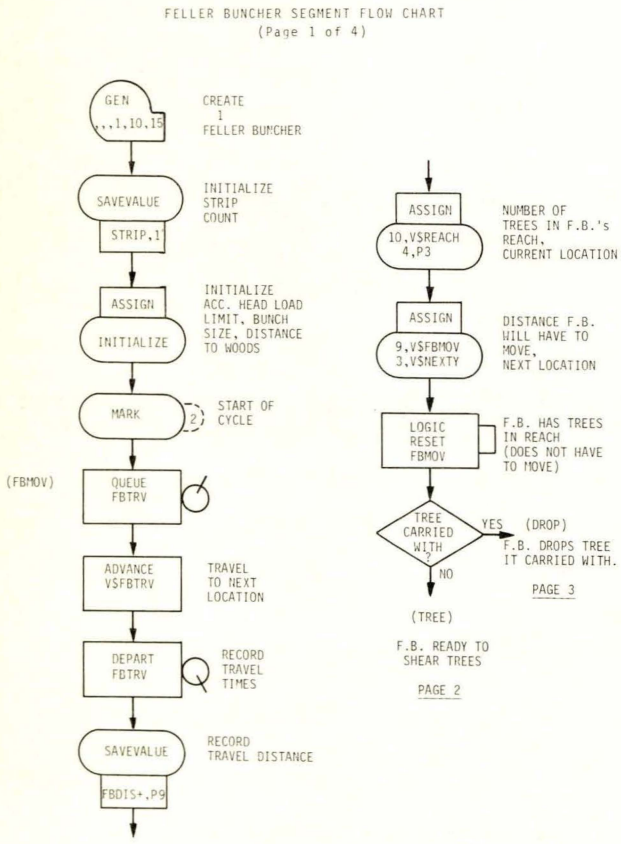
```
/ * * * INPUT DATA
*
*
 FBTRV FVARIABLE  P9*100/V$SPEED          TRAVEL TIME (DIST/SPEED) IN CENTIMIN,
*                                                  P9 = DISTANCE
 SPEED FVARIABLE  XSFTRV1+XSFTRV2*FN$$NORM/10    FELLER BUNCHER TRAVEL
 FBSHR FVARIABLE  FN$FBSHR                POSITION & SHEAR TIME
 FBDRP FVARIABLE  FN$FBDRP                SWING AND DROP TIMES
*
 ACCLM FVARIABLE  FN$ACCLM                ACCUMULATOR HEAD LIMIT
 BUNLM FVARIABLE  XSBNLMT                 SKIDDER BUNCH SIZE LIMIT
*
*
 REACH FVARIABLE  FN$REACH                NUMBER OF TREES WITHIN REACH
 FBMOV FVARIABLE  FN$FBMOV                DIST FB MUST MOVE TO REACH MORE TREES
 TDIAM FVARIABLE  FN$DBH                  SUPPLIED FROM STAND DBH DATA
 MCDLY FVARIABLE  FN$MCDLY                MECHANICAL DELAY
 NMDLY FVARIABLE  FN$NMDLY                NON-MECHANICAL DELAY
 STPLN VARIABLE   XS$TPLN
 TVOL  FVARIABLE  (133*P8*P8-283)/10      TREE VOL IN TERMS OF DIA(P8)
*                                         100 TH'S OF CU FT,
*
*         DEFINING FUNCTIONS - MACHINE DATA
*
*     THIS INPUT DATA WAS OBTAINED FROM ACTUAL TIME STUDIES
*          CARRIED OUT IN 1978
 ACCLM FUNCTION   RN2,D5                  # TREES IN ACC HEAD
,22,1/.45,2/.73,3/.9,4/1,5
*        POSITION AND SHEAR - PER STEM  TIME IN CENTI-MIN
 FBSHR FUNCTION   RN2,C9
0,0/.29,10/.68,20/.86,30/.97,40/.98,50/.99,60/.995,70/1.0,90
*
*        SWING AND DROP   TIME IN CENTI-MIN
 FBDRP FUNCTION   RN2,C8
0,0/.13,10/.60,20/.95,30/.98,40/.99,50/.995,60/1.0,70
*
*         DEFINING FUNCTIONS - STAND DATA
*
 DBH   FUNCTION   RN4,D7                  TREE DIAMETER  INCHES
.05,3/.28,4/.58,5/.82,6/.96,7/.99,8/1.0,9
*
 REACH FUNCTION   RN3,C12                 TREES IN REACH AT A GIVEN SPOT
0,27.03,4/.1,6/.2,8/.6,16/.68,18/.75,20/.81,22/.86,24/.9,26/.95,30/1,36
*
 FBMOV FUNCTION   RN3,C9                  DISTANCE FELLER MUST MOVE
0,0/.1,5/.25,10/.55,25/.75,35/.85,50/.9,60/.95,90/1.,120
*
 MCDLY FUNCTION   RN6,D11                 MECHANICAL DELAY
.99,0/.991,50/.992,100/.993,150/.994,200/.995,250/.996,500/.997,1000
.998,2000/.999,3000/1.0,4000
*
 NMDLY FUNCTION   RN6,D13                 NON-MECHANICAL DELAY
.985,0/.987,15/.989,25/.991,35/.992,40/.993,50/.994,75/.995,80/.996,100
.997,200/.998,300/.999,400/1.0,500
*
* * * * INITIAL CONDITIONS FOR STAND
*
*                 INITIAL DATA TAKEN FROM MPH TIME STUDY
       INITIAL    XSAVDBH,550           AVE. DBH  (IN)*100
       INITIAL    XSAVHGT,43            AVE. TREE HGT. APPROX 42'
       INITIAL    XSAVVOL,345000        CU FT/ACRE*100
       INITIAL    XSTRPAC,884           TREES/ACRE
       INITIAL    XSSTPLN,955           AVE. STRIP LENGTH
       INITIAL    XSMVSTP,55            DISTANCE BETWEEN STRIPS
       INITIAL    XSLBCFT,55            LB PER CU FT - RED MAPLE
       INITIAL    XSWKDAY,8             HRS IN A WORK DAY
*
* * * * INITIAL CONDITIONS FOR EQUIPMENT -DATA TAKEN FROM USFS MPH TIME STUDY
*
       INITIAL    XSACLMT,4             MAX # TREES IN ACC LOAD
       INITIAL    XSBNLMT,120           MAX ATTEMPTED SKID BUNCH SIZE
       INITIAL    XSFTRV1,49            MEAN TRAVEL SPEED  FT/MIN
       INITIAL    XSFTRV2,19            STD. DEV. TRAVEL SPEED  FT/MIN
       INITIAL    XSFBGPH,55            FB  GAL/HR*10
       INITIAL    XSFBTYP,0             DROTT 0   RUBBER TIRED 1
       INITIAL    XSFBOUT,100           DIST FB TRAVELS TO WOODS
*
*
       RMULT      4,,37
       START      5,,5,1
       END
```

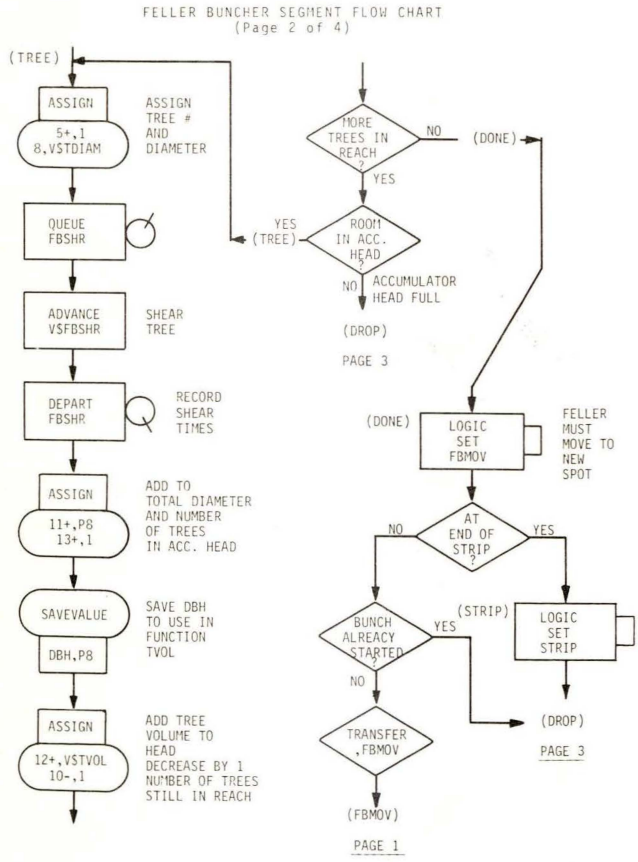
```
1*            SUBROUTINE SYSTM(IX)
2*            DIMENSION IX(5)
3*            DATA I/0/
4*      C
5*          1 FORMAT(1H1,43X,'FULL  TREE  FIELD  CHIPPING  ',
6*           A 'SIMULATOR'/1H0,58X,'DEVELOPED  BY  THE'/1H ,46X,'NORTH CENTRAL '
7*           B,'FOREST  EXPERIMENT  STATION'/1H ,44X,'FOREST  SERVICE, U. S. DEP
8*           C'T.  OF  AGRICULTURE'//1H0,29X, 'FOREST  PRODUCTS  MARKETING  AND
9*           TUTILIZATION  PROJECT,  DULUTH,  MINNESOTA'/1H ,61X,'AND  THE'/1H ,
10*          E40X,'FOREST  ENGINEERING  LABORATORY, HOUGHTON,  MICHIGAN'/1H0,62X
11*          F,'AUTHORS '/1H ,52X,'DENNIS P. BRADLEY, ECONOMIST'/1H ,51X,'SHARON
12*          G A. WINSAUER, PROGRAMMER'//)
13*     C
14*         2 FORMAT(1H0,'I.  STAND CHARACTERISTICS.'//1H0, F12.2,' CU FT. ',
15*           A  'AVERAGE VOLUME'
16*           B' PER ACRE.'/1H0,F12.2,' INCHES, AVERAGE DBH.'/1H0,F12.2,' FEET,',
17*           C' AVERAGE TREE HEIGHT.'/1H0,F12.2,' AVERAGE NUMBER OF TREES ',
18*           D'PER ACRE.'/1H0,F12.2,' FEET, AVERAGE TREE SPACING.'/)
19*     C
20*         3 FORMAT(1H0,'II.  SYSTEM CHARACTERISTICS AS SPECIFIED BY THE ',
21*           A'ANALYST.'//1H ,2X,'A.  FELLER-BUNCHER.',10X,I10,'  MACHINE',
22*           B  5X,'TRACKED TYPE-ROTATABLE BOOM WITH ACCUMULATOR SHEAR'
23*           C  , //9X,'MACHINE LIMITATIONS '/)
24*     C
25*         4 FORMAT(1H0,'II.  SYSTEM CHARACTERISTICS AS SPECIFIED BY THE ',
26*           A'ANALYST.'//1H ,2X,'A.  FELLER-BUNCHER.',10X,I10,'  MACHINE',
27*           B5X,'RUBBER-TIRED TYPE',//,9X,'MACHINE LIMITATIONS.'/)
28*     C
29*         5 FORMAT(1H , 14X, 'THE SHEAR CAN HANDLE ONLY ONE TREE.')
30*     C
31*         6 FORMAT( 1H , 10X, 'THE ACCUMULATOR-SHEAR WILL TRY TO OBTAIN',
32*           A ' A LOAD OF UP TO',F6.1,' TREES')
33*     C
34*         7 FORMAT(1H0,8X,'BUNCH LIMITATIONS DICTATED BY SKIDDER CAPACITY:'/
35*           A1H0, 10X,'THE FELLER-BUNCHERS TRY TO ACHIEVE',
36*           B ' SKIDDER BUNCHES WITH A TOTAL SUM OF DIAMETERS EQUAL TO',
37*           C F6.1, ' INCHES')
38*     C
39*     C
40*           X1 = IX(1)
41*           X2 = IX(2)
42*           X3 = IX(3)
43*           X4 = IX(4)
44*           X5 = IX(5)
45*           I = I + 1
46*           IF ( I .GT. 2 ) I = 1
47*           GO TO (10,20),I
48*     C
49*        10 CONTINUE
50*           AVVOL= X1/100.
51*     C AVVOL = AVERAGE VOLUMN PER ACRE = CUFT.
52*           AVDBH= X2/100.
53*     C ACDBH = AVERAGE DBH = INCHES
54*           AVHGT=X3
55*     C AVHGT = AVERAGE TREE HEIGTH = FEET
56*           TRPAC=X4
57*     C TRPAC = AVERAGE NUMBER TREES PER ACRE
58*           TRSPC=(43560./TRPAC)**.5
59*     C TRSPC = AVERAGE TREE SPACING = FEET
60*           WRITE (6,1)
61*           WRITE(6,2) AVVOL,AVDBH,AVHGT,TRPAC,TRSPC
62*           RETURN
63*     C
64*        20 CONTINUE
65*           NUMFB=1
66*     C NUMFB = NUMBER OF FELLER-BUNCHERS
67*           ACCLM =  X2
68*     C ACCLM ACCUMULATOR LIMIT SUM OF DBH
69*           FBTYP=X3
70*     C  FBTYP  FELLER BUNCHER TYPE  0 = DROTT  1 = RUBBER-TIRED TYPE
71*           BUNLM = X4
72*     C  BUNLM  BUNCH SIZE LIMIT
73*           IF(FBTYP.EQ.0)WRITE(6,3)NUMFB
74*           IF(FBTYP.EQ.1)WRITE(6,4)NUMFB
75*           IF (ACCLM .LT. 1.) WRITE(6,5)
76*           IF (ACCLM .GE. 1.) WRITE(6,6) ACCLM
77*           WRITE(6,7) BUNLM
78*           RETURN
79*     C
80*           END
```

```
      SUBROUTINE FELBN (IX)
      DIMENSION IX(5)
      DATA I/0/
      INTEGER FBACC,FBDIS,BNCOM
C
    1 FORMAT (1H1,4X,'F E L L E R - B U N C H E R   P R O D U C T',
     A' I O N   A N D   C O S T   S U M M A R Y',///,1H ,132('*'),////
     B//,1H,'I.    A.',F8.2,5X,'HOURS WORKED BY FELLER-BUNCHER(S)'
     1 ' INCLUDING'//16X,F8.2,
     2 5X,     'MINUTES OF PERSONAL BREAKS, ',//16X,F8.2,
     3   5X,   'MINUTES MECHANICAL DELAY, ',/  / 16X,F8.2,
     4 5X,     'MINUTES NON-MECHANICAL DELAY',
     C//,7X,'B.',I8,5X,'FELLER-BUNCHER.',5X,
     D 'TRACKED TYPE-ROTATABLE BOOM WITH ACCUMULATOR SHEAR'///)
C
    2 FORMAT (1H1,4X,'F E L L E R - B U N C H E R   P R O D U C T',
     A' I O N   A N D   C O S T   S U M M A R Y',///,1H ,132('*'),////
     B//,1H,'I.    A.',F8.2,5X,'HOURS WORKED BY FELLER-BUNCHER'
     1 ' INCLUDING'//16X,F8.2,
     2 5X,     'MINUTES OF PERSONAL BREAKS, ',//16X,F8.2,
     3   5X,   'MINUTES MECHANICAL DELAY, ',/  / 16X, F8.2,
     4 5X,     'MINUTES NON-MECHANICAL DELAY',
     C//,7X,'B.',I8,5X,'FELLER-BUNCHER.',5X,
     D'RUBBER-TIRED TYPE.'///)
C
    3 FORMAT(1H,'II.   A.',I8,5X,'TOTAL ACCUMULATOR CYCLES COMPLETED',
     A' = ALL MACHINES.',//,16X,F8.2,5X,'AVERAGE NUMBER OF TREES PER',
     B' CYCLE.',//,16X,F8.2,5X,'AVERAGE VOLUME PER CYCLE = CU.FT.',//)
C
    4 FORMAT(1H,6X,'B.',I8,5X,'BUNCHES COMPLETED',///,
     A16X,F8.2,5X,'AVERAGE NUMBER OF TREES PER BUNCH.',/)
C
    5 FORMAT(1H,15X,F8.2,5X,'AVERAGE NUMBER OF CYCLES PER BUNCH.',/)
C
    6 FORMAT(1H,15X,F8.2,5X,'AVERAGE VOLUME PER BUNCH = CU.FT.',///,
     A7X,'C.',I8,5X,'TOTAL TREES FELLED.',//,7X,'D.',F8.1,5X,
     B'TOTAL VOLUME FELLED = CU.FT.',//,7X,'E.',
     CF8.2,5X,'TOTAL TONS FELLED',//,7X,'F.',I8,5X,
     D  'TOTAL DISTANCE TRAVELED = FEET',///)
C
    7 FORMAT(1H,'III.  A.',F8.2,5X,'AVERAGE NUMBER OF CYCLES PER',
     A' MACHINE HOUR.',/)
C
    8 FORMAT(1H,6X,'B.',F8.2,5X,'AVERAGE NUMBER OF BUNCHES COMPLETED',
     A' PER MACHINE HOUR.',//,7X,'C.',F8.2,5X,'AVERAGE NUMBER OF',
     B' TREES FELLED PER MACHINE HOUR.',//,7X,'D.',F8.2,5X,'AVERAGE',
     C' VOLUME FELLED PER MACHINE HOUR.',//,7X,'E.',F8.2,5X,'AVERAGE',
     D' NUMBER OF TONS FELLED PER MACHINE HOUR.',//,7X,'F.',F8.2,5X,
     E'AVERAGE DISTANCE TRAVELED PER MACHINE HOUR = FEET.',///)
C
C
   11 FORMAT(1H,'IV.   A.',F8.2,5X,'TOTAL GALLONS OF FUEL USED BY',
     A' THE FELLER-BUNCHER.',//,16X,F8.2,5X,'GALLONS PER HOUR.',///,16
     BX,F8.2,5X,'GALLONS PER TON.',//,16X,F8.2,5X,'GALLONS PER CUNIT.')
C
      X1 = IX(1)
      X2 = IX(2)
      X3 = IX(3)
      X4 = IX(4)
      X5 = IX(5)
      I = I + 1
      IF (I .GT. 3) I = 1
      GO TO (10,20,30),I
   10 CONTINUE
      NUMFB = 1
C NUMFB =  NUMB. OF FELLER-BUNCHERS
      FBTYP = X3
C  FELLER-BUNCHER TYPE  0 = DROTT  1 = RUBBER-TIRED TYPE
```

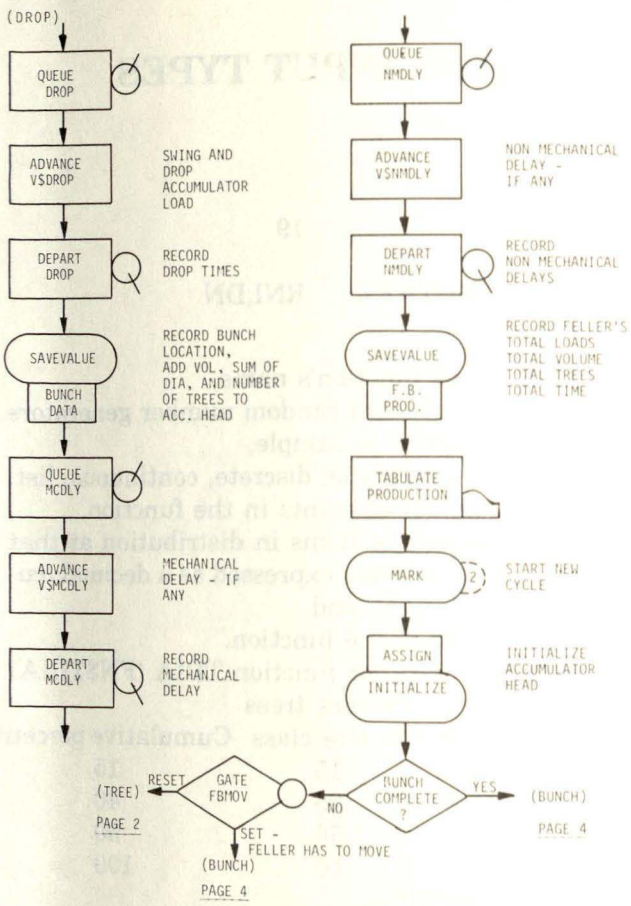
```
      C  BREAK AND DELAY TIMES IN MINUTES
          BREAK=X3/100
          DELAY=X4/100
          DELNM=X5/100
          RETURN
       20 CONTINUE
          NTREE =  X1
          FBVOL = X2/100.
      C FBVOL =   VOL. FELLED ALL MACHINES
          FBCNT = FBVOL/100.
      C  FBCNT  FELLER-BUNCHER VOL. IN CUNITS.
          BNCOM = X3
      C BNCOM =  BUNCHES COMPLETED
          FBHR = X4/100.
          FBDIS =  X5
      C FBDIS =   DIST. TRAV. ALL MACHINES
          RETURN
       30 CONTINUE
          FBACC = X1
      C  FBACC  NUMBER OF ACCUMULATOR COMPLETED CYCLES.
          XDEN = X2
      C  POUNDS OF WOOD PER CUBIC FOOT.
          FBTNS = X3*XDEN/200000
          FBGPH = X4/10
      C  FELLER-BUNCHER TOTAL GALLONS USED
      C  FELLER-BUNCHER VOL. IN TONS
      C
          IF( FBTYP.EQ.0 )WRITE(6,1)FBHR,BREAK,DELAY,DELNM,NUMFB
          IF( FBTYP.EQ.1 )WRITE(6,2)FBHR,BREAK,DELAY,DELNM,NUMFB
      C
          FBTPC = NTREE*1./FBACC
      C  FBTPC  TREES PER CYCLE
          FBVPC = FBVOL/FBACC
      C  FBVPC  VOLUME PER CYCLE
          WRITE(6,3)FBACC,FBTPC,FBVPC
      C
          FBTPB =  NTREE*1./BNCOM
      C FBTPB =  AVE. TREES PER COMPLETED BUNCH.
          WRITE(6,4)BNCOM,FBTPB
      C
          FBCPB = FBACC*1./BNCOM
          WRITE(6,5)FBCPB
      C
          FBVPB = FBVOL/BNCOM
      C FBVPB =  AVE. VOL. PER BUNCH
          WRITE (6 ,6) FBVPB,NTREE,FBVOL,FBTNS,FBDIS
      C
          CYCHR = FBACC/FBHR
          WRITE(6,7)CYCHR
      C
          FBBMH = BNCOM/FBHR
      C FBBMH = AVE. BUNCHES PER MACHINE HOUR
          FBTMH = NTREE/FBHR
      C FBTMH = TREES FELLED PER MACHINE HOUR
          FBVMH = FBVOL/ FBHR
      C FBVMH = VOL. FELLED PER MACHINE HOUR
          FBATH = FBTNS/FBHR
      C  FBATH  AVERAGE TONS PER HOUR
          FBDMH = FBDIS/FBHR
      C FBDMH = DIST. TRAV. PER MACHINE HOUR
          WRITE (6 ,8) FBBMH,FBTMH,FBVMH,FBATH,FBDMH
      C
      C  FELLER-BUNCHER GALLONS/HOUR
          FBGPT = FBGPH/FBATH
      C  FELLER-BUNCHER GALLONS PER TON
          FBGPC = FBGPH/(FBVMH/100)
      C  FELLER-BUNCHER GALLONS PER CUNIT
          FBTGU = FBGPH*FBHR
          WRITE(6,11)FBTGU,FBGPH,FBGPT,FBGPC
          RETURN
          END
```

APPENDIX C
COMPLETE FLOW CHARTS

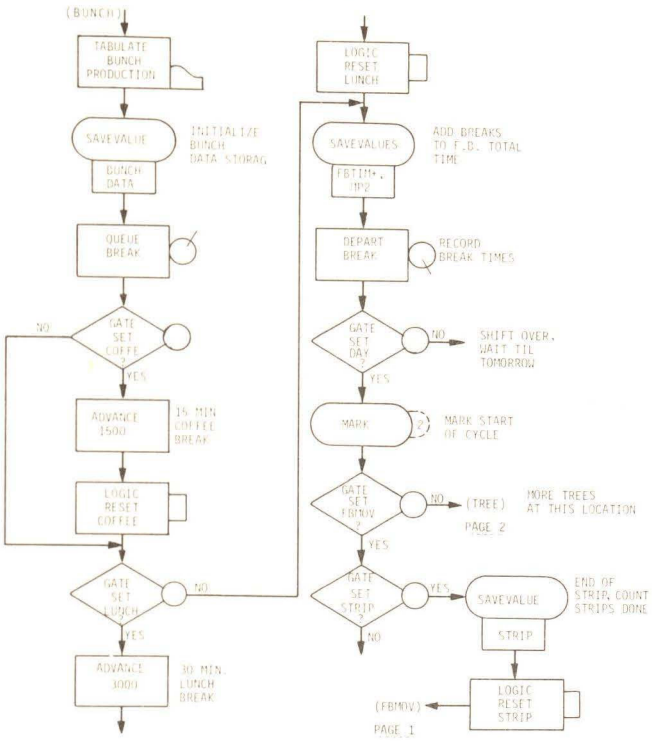




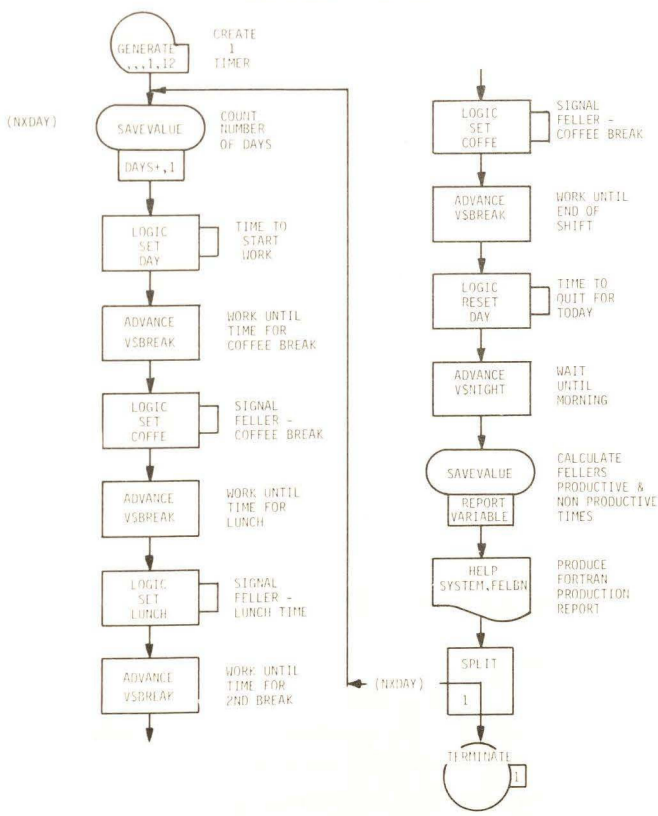
FELLER BUNCHER SEGMENT FLOW CHART
(Page 3 of 4)



FELLER BUNCHER SEGMENT FLOW CHART
(Page 4 of 4)



TIMER SEGMENT FLOW CHART



APPENDIX D

CARD FORMATS AND SOME GPSS INPUT TYPES

INPUT TYPES AND CARD FORMATS

For more detailed information see a GPSS manual.

1. SAVEVALUES

Savevalues are integers that can be accessed at any time during the run. In the program their form is X$NAME where NAME is the particular savevalue of interest.

Savevalues may be set to zero before the run begins, or may be given an initial value, X. This is done with an initial card of the format:

Col. 8 19

INITIAL X$NAME,X

INITIAL X$AVDBH,5

Sets the savevalue AVDBH to 5.

Note: These INITIAL cards must follow all other cards in the deck except the RMULT and START cards.

2. VARIABLES

Variables are used to calculate integers anytime they are called during the run; they can be defined as algebraic equations in terms of constants, savevalues, functions, or even other variables. They must be defined at the outset with the following card format:

Col.
2 8 19

NAME FVARIABLE Defining equation

TVOL FVARIABLE 133*X$DBH*X$DBH/10

This defines that tree volume will be calculated by TVOL = 13.3 $(DBH)^2$.

During the simulation run, variables are called and computed by using V$NAME; for example:

Col. 8 19

TABULATE V$TVOL.

3. FUNCTIONS

Functions supply distributions to the program. They are called in the program by FN$NAME where NAME is the particular function of interest. There are several types of functions available; only one sample, a discrete function, will be given here.

Functions consist of two or more cards:

Col.
2 8 19

NAME FUNCTION RNI,DN
.X1,V1/.X2,V2/...

NAME is the function's name,
RNI = one of eight random number generators assigned to sample,
D = function type: discrete, continuous, list,
N = number of points in the function,
XI = percent of items in distribution at that value or less expressed as a decimal (cumulative), and
VI = value of the function.

For example, Data for function TDIA (FN$TDIA):

Tree diameter	Percent trees in size class	Cumulative percent
4	15	15
5	25	40
6	50	90
7	10	100

Card image forGPSS:

Col.
2 8 19
TDIA FUNCTION RNI,D4
15,41/.4,5/.9,6/1.0,7.

4. RMULT and START

GPSS has eight random number generators available for use in the model. This allows use control over the sampling from distributions, making it possible to harvest the same stand repeatedly while isolating the effect of a change in one of the machine parameters, such as travel speed. The RMULT cards control the start of the sequence for each random-number generator.

The START card controls the number of days the simulation will run and the standard GPSS output.

The card formats are as follows:

Col. 8 19
RMULT A,B,C,D,E
START N,,S,1

A,B,C, etc., controls the sequence for random number generator, 1, 2, 3, etc., respectively.

N = number of days the simulation is to run, and
S = number of days between standard outputs.

U.S.GPO:1981-766-507/133-6

Winsauer, Sharon A.

1980. A program and documentation for simulation of a tracked feller/buncher. U.S. Department of Agriculture Forest Service, Research Paper NC-192, 26 p. U.S. Department of Agriculture Forest Service, North Central Forest Experiment Station, St. Paul, Minnesota.

Presents a computer model written in GPSS (General Purpose Simulation System) designed to simulate and study the productivity and operation of a tracked feller/buncher.

KEY WORDS: GPSS (General Purpose Simulation System), computer, harvesting, productivity, modeling.